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VAN. H. MANNING, DIRECTOR

SHOT FIRING IN COAL MINES BY ELECTRICITY CONTROLLED FROM OUTSIDE

BY

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AND

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SHOT FIRING IN COAL MINES BY ELECTRICITY CONTROLLED FROM OUTSIDE.

By H. H. Clark, N. V. Breth, and C. M. Means.

INTRODUCTION.

For the sake of brevity the system of shot firing discussed in this paper is termed "outside-firing system" or "outside system."

The purpose of an outside shot-firing system is to provide means for firing the shots when no one is in the mine, in order to eliminate completely any risk to life that may attend blasting. The system is intended as a safety measure and for that reason has been investigated by the Bureau of Mines.

This paper does not discuss the merits of the outside-firing system as compared with other measures for insuring safety to underground workers, but reviews the principal features of some existing outside firing systems, in order to set forth the essential features that should be considered in the design and installation of such a system, and to advocate practices that will assure the satisfactory accomplishment of its purpose.

The existing systems described herein are not necessarily held up as models, although the operation of most of them has been gratifyingly successful.

GENERAL DESCRIPTION OF OUTSIDE SHOT-FIRING SYSTEM.

An outside firing system consists of a source of electric power outside the mine, conductors leading from the surface to all working places, and a system of switches for keeping the lines free from stray currents and from the firing current until all men have withdrawn from the mine. The most complete systems employ switches at or near the entrance to rooms and working places, at the mouth of each cross entry, and at the point underground where the shot-firing circuit enters the mine. At that point there is also established a break in the circuit to guard against discharges of lightning. The break is usually accomplished by providing flexible conductors, about 6 feet long, so arranged that they can be readily disconnected from the circuit and locked in the open-circuit position until all other underground connections and switches have been closed. In addition there are provided on the surface a switch for connecting the

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shot-firing system to the power supply and another switch to be operated for the actual firing of the shots.

This system allows the firing circuits to be completed step by step, beginning at the working places and progressing toward the mine entrance. The underground circuits are therefore not complete until the switch at the mine entrance has been closed and the 6-foot break, mentioned above, has been bridged across. The system as a whole is not connected to the source of electric power until it has been ascertained (by a suitable checking system) that all men are out of the mine. Even then it is still necessary for the man commissioned to fire the shots to close a locked control switch mounted in an inclosure to which he alone has access. Thus the discharge of blasts by stray currents is prevented by the room and entry switches, the discharge of blasts by lightning is prevented by the 6-foot break at the mine entrance, and the discharge of blasts by accidental connection to the shot-firing generator is prevented by all these switches as well as by the two switches that are placed on the surface.

DESCRIPTIONS OF SOME SYSTEMS NOW IN USE.

Following is a description of some of the outside shot-firing systems already installed in the mines of Utah, New Mexico, Oklahoma, Alabama, and Kansas. A number has been ascribed to each different system, and in subsequent references to any system described the number only is given. Different terms are used at the various mines described to designate the men who have charge of the shot firing and operate the shot-firing systems. The duties of the men are not the same at each mine, and the actual firing of the shots occupies an exceedingly small part of their working hours. Therefore it has seemed best to the Bureau of Mines to adopt for this report the term "shot boss" to designate the man who is charged with the operation of the shot-firing system. The use of this term draws a distinction clearly between the man who operates a shot-firing system and the "shot firer" who goes from place to place underground discharging a few shots at a time.

SYSTEM 1.

The essential details of the outside shot-firing system designated "system 1" follow:

CHECK CABIN.

The check cabin of the mine using system 1 is placed at the manway entrance to the mine and has a single attendant, whose duty it is to see that each man receives his identification check when he enters the mine and deposits it when he leaves. The cabin also contains the shot-firing switch, installed in a locked box.

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SOURCE OF POWER.

The 500-volt direct-current power used for firing shots is supplied from a power-house generator of large capacity, the connecting line from which is controlled by a locked switch at the mine.

SHOT-FIRING CIRCUITS.

The main shot-firing circuit runs from the locked switch that connects with the power house to the check cabin, and thence overland on poles to a bore hole that opens into the 27th entry of the mine near the main slope. From this point the main circuit follows the slope. At each cross entry a branch circuit is tapped, without switches, from the main circuit. The branches run to the face of the entry. Short leads ending in plugs are tapped from the entry circuit at each room entrance. The room circuit can be opened or closed by removing or inserting the plugs in sockets in which the room wires terminate.

The main circuit from the power house to the bore hole is No. 10 (B. & S.) rubber-covered copper wire. Five hundred and thirty feet of No. 4 (B. & S.) duplex machine cable is used in the bore hole. Starting at the bottom of the bore hole and extending for 1,800 feet, No. 6 (B. & S.) rubber-covered iron wire is used. The rest of the main circuit and all cross-entry circuits are No. 10 rubber-covered copper wire. The room circuits are No. 14 rubber-covered copper wire.

The circuits on the main and cross entries are supported on porcelain knobs fastened to wooden cross arms secured to the roof. The wires in the rooms are hung on the props without the use of insulators.

SWITCHES.

There are only six switches in the entire shot-firing system. They are all installed in the main circuit. The switches are placed in locked boxes, situated as follows:

One double-pole switch in the power house; one single-pole shot-firing switch in the check cabin; one double-pole switch at the 27th west entry near the bottom of the bore hole through which the shot-firing circuits enter the mine; one double-pole switch in the main circuit at the 29th entry; one at the 32d entry; and one at the 35th entry. Connection to the switch near the bottom of the bore hole is made by flexible leads, which can be disconnected so as to leave a gap 8 feet long as a protection against lightning. There are no room switches, the plug connection previously described serving that purpose.

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METHOD OF OPERATION.

The shot firers distribute the detonators during the day and the miners are allowed to connect the detonators to the room wires. When the miner leaves his room after having connected his shots he inserts in the sockets in which his room wires terminate the plugs that are connected to the circuit in the entry. When all the men are in the man trip the shot firer unlocks and closes the last inby switch in the main circuit and closes the other switches as he comes to them on his outward trip. When the shot firer gets outside he and the check man go over the check board twice to make sure that all the men are out of the mine. When all the men have been accounted for, the shot firer proceeds to the power house, where he unlocks and closes the switch that connects the shot-firing circuit to the power circuit. He then returns to the check cabin, where the shot-firing switch is placed, and unlocks and closes the shot-firing switch. The switch is left closed for eight seconds and is then opened and locked, as is also the switch that connects to the power circuit.

Having completed these operations, the shot firer goes off duty. The switches inside the mine are opened in the morning by the assistant mine foreman.

MISCELLANEOUS DETAILS.

The shots are connected in multiple, and the whole mine is shot at once.

The coal is undercut and is shot down with permissible explosives.

The average number of shots fired per day is 158. The average proportion of missed shots is about 3 per cent.

There are three shot firers, who are on firing duty a week at a time. The acting shot firer extends and repairs the circuits; the other two distribute the detonators.

It is the practice of one of the shot firers to close the shot-firing switch only once when the shots are fired; the other two shot firers make a practice of closing the switch twice. Seemingly, each has the same degree of success.

COST OF OPERATION.

The cost of operation and maintenance of the shot-firing system is stated by the mine officials to be 0.8 cent per ton of coal mined.

SYSTEM 2.

CHECK CABIN.

The check cabin of the mine using system 2 is situated near the top of the shaft. There is no attendant. Each miner when entering the mine removes his identification check from the check board, and when leaving the mine replaces it.

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SOURCE OF POWER.

The power for firing the shots is supplied by a 50-kw., 250-volt, direct-current generator placed in the engine room. It is excited to only 175 volts when used for shot-firing service.

SHOT-FIRING CIRCUITS.

The main shot-firing circuit runs from the engine room to the top of the shaft, then down the shaft and along the main entry. At each cross entry a branch circuit is tapped from the main circuit. These branches run to the face of the entry. The main circuit is No. 10 (B. & S.) rubber-covered wire. For the cross-entry circuits No. 12 (B. & S.) rubber-covered duplex copper wire is used. For wiring No. 10 (B. & S.) iron wire covered with triple weatherproof braid is used.

From the engine room to the top of the shaft the main circuit is carried in a conduit, down the shaft it is carried in lead-covered cable, and on the main entry it is carried in a conduit. The cross-entry circuits are run under the ball of the rail in most places. This placing of the wires was chosen because frequent falls of roof made it impracticable to run the shot-firing circuits along the roof. The mine is extremely dry, which probably accounts for the success that attends this method of installing wires. In some places the lines are carried on porcelain insulators fastened to plugs driven into the coal.

In wiring the rooms the wires are supported on props in some places and in others are laid directly on the bottom; the fact that satisfactory operation is obtained with wires lying on the bottom is due to the extreme dryness of the mine and the comparatively low voltage in the room circuits.

SWITCHES.

The shot-firing system includes the following switches, only one of which is locked: One placed in the engine room on the power switchboard; two in series placed in the engine room on the shot-firing switchboard (one of these is used for firing and is called the firing switch); and one, a locked switch, placed at the bottom of the shaft. The remainder of the controlling equipment of the shot-firing system consists of relays, placed at each cross entry, which automatically connect to the shot-firing circuit different sections of the mine one after another. The operation of the relays does not require the opening of the inclosure in which they are mounted. The covers of these inclosures are fastened with screws, but are not provided with locks. There are no cross-entry switches and no room switches, but a gap has been provided in the circuit to protect against lightning discharges.

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METHOD OF OPERATION.

A miner after connecting his shots to the room wires must set the relay (placed at the mouth of the entry) in the firing position by pushing in an aluminum plunger that projects from the side of the relay casing. It is necessary to push this plunger only once to set the relay for firing the shots on the entry that it controls. The control is therefore in the hands of the miners as far as the locked switch at the bottom of the shaft. As the shot firer leaves the mine he unlocks and closes the switch at the foot of the shaft. He then goes to the surface and examines the check board to see that the men are all out of the mine. After making sure of this fact he instructs the engineer to start the generator, which up to that time has not been running. After the generator has been started and excited to 175 volts, the shot firer closes the switch on the generator switchboard and the two switches on the shot-firing switchboard. The closing of these switches discharges the shots connected to the first relay. The one of these switches that is used as a firing switch is then alternately opened and closed as many times as there are relays in the shot-firing circuit. The opening of the firing switch causes the relay last fired to close the circuit to the next relay to be fired, and the closing of the firing switch fires the shots connected to this relay, which then automatically opens one side of the circuit on the entry that has just been fired. After the shots have been fired, all switches in the power house are opened and the generator is stopped. The locked switch at the bottom of the shaft is then opened.

MISCELLANEOUS DETAILS.

The coal is shot from the solid with black powder.

The shots are connected in multiple.

There are about 200 shots fired per day with about 2 per cent of failures.

Information regarding the cost of operation of system 2 was not available.

SYSTEM 3.

CHECK CABIN.

In connection with system 3 no checking system is employed at the mine for keeping track of the men underground. The men when leaving the mine report to the mine foreman anyone who is going to be late in getting out of the mine. This system of accounting for the men has so far been free from accidents, possibly because the shots are not fired until 3½ hours after the end of the regular day shift.

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SOURCE OF POWER.

The 500-volt direct-current power used for firing the shots is obtained from the line of a street railway company.

SHOT-FIRING CIRCUITS.

The main circuit starts at the tracks of the railway company and runs to the shot-firing cabin, a small wooden inclosure for the shot-firing switch. One side of the circuit is connected to the trolley wire and the other side to the track rail. From the shot-firing cabin the circuit enters the mine by the main slope and follows the slope to the face. Branch circuits are tapped from the main circuit at each cross entry.

The main circuit is No. 6 (B. & S.) copper wire with weatherproof covering. For the cross-entry and room circuits No. 12 (B. & S.) copper wire with weatherproof covering is used.

From the trolley line to the mouth of the mine the circuit is carried on poles and supported on glass insulators. The main circuits inside the mine are supported on wooden clamps instead of insulators. The cross-entry and room circuits are supported on nails driven into the props. The success that attends this uncommendable practice must be attributed to the extreme dryness of the mine.

Lightning arresters are placed outside the mine on the main circuit. A gap for lightning protection is provided in the underground circuits.

SWITCHES.

The shot-firing circuits are controlled by the following double-pole switches, all of which are locked: One at the railway tracks, one and fuses in the shot-firer's cabin, one at the entrance to the mine, and one at each cross entry. The cross-entry switches have porcelain bases. No room switches are used, but there are no power wires on the room entries, and the necessity for room switches is therefore not apparent.

METHOD OF OPERATION.

At the end of the regular day shift the two night fire runners, who are also the shot preparers and firers, start on their regular runs, inserting, tamping, and connecting the shots. When these men have finished their work, they come out of the mine together, closing the cross-entry switches as they come, and finally closing the switch at the mine entrance. After the switch at the railway tracks has been unlocked and closed, the shot-firing switch is closed and kept so until the fuses have blown. The switch is then opened, new fuses are inserted, and the operation is repeated. The switch is then opened

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and locked; the fire runners then examine the mine for fire, opening the shot-firing switches as they proceed. If any shots have failed to explode, the trouble is located and remedied, and when the fire runners again leave the mine they make a second attempt to fire the missed shots.

MISCELLANEOUS DETAILS.

The coal is shot from the solid with black powder.

There are about 135 shots fired each day. Information regarding the number of missed shots was not available.

All the shots in the mine are fired at once.

The shots are connected in multiple.

Information regarding the cost of operation of system 3 was not available.

SYSTEM 4.

CHECK CABIN.

The check cabin of the mine using system 4 is situated about 150 feet from the entrance to the mine and is provided with an attendant. Each man who enters the mine places his identification check on the check board and when leaving the mine removes his check and takes it with him.

SOURCE OF POWER.

The 550-volt direct-current power used for firing the shots is supplied by the regular power generators.

SHOT-FIRING CIRCUITS.

The main circuit runs from the power house to the shot firer's cabin, a small wooden inclosure for the shot-firing switch. From this point the circuit follows the return airway into the mine. Branch circuits are tapped from the main circuit at each cross entry and run to the face of the entry. Room wires are tapped from the branch circuits at each room neck.

The main circuit from the power house to the entrance of the mine is No. 6 (B. & S.) rubber-covered copper wire. From the entrance of the mine to the working part of the mine a pair of No. 4 (B. & S) power cables is used for the main circuit. For the branch circuits No. 6 and No. 10 (B. & S.) rubber-covered copper wire and No. 12 (B. & S.) weatherproof wire are used. For the room circuits No. 14 (B. & S.) weatherproof wire is used, and for the room circuits No. 14 (B. & S.) rubber-covered copper wire.

The branch circuits are supported on porcelain insulators secured to cross arms fastened to the roof by means of expansion bolts or lag screws. The room circuits are supported on the props without the use of insulators.

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SWITCHES.

The shot-firing circuits are controlled by the following switches: One double-pole switch in the power house; one double-pole switch in the shot-firing cabin, and two double-pole switches in series at each cross entry. The shot-firing switch and one of the switches at each cross entry are inclosed in locked boxes. There are no room switches, although there are power wires in the room entries. There is no gap in the underground circuits as a safeguard against lightning.

METHOD OF OPERATION.

The shot inspectors, one of whom acts as shot firer, distribute the detonators during the day, and the miners are allowed to connect the detonators to the room wires. At 6 p. m. the fan man outside the mine shuts off all power entering the mine, the shot firers being apprised of this fact by the stopping of the booster fan and the extinction of the electric lights. The shot firers then close the switches at each cross entry and leave the mine. The shot inspector, who acts as shot firer, switches on red electric lights at the mine entrance and at the shot-firing cabin to give warning that the shots are about to be fired. He then unlocks and closes the firing switch, which previously has been energized from the power house, and at once reopens and relocks it.

After the shots have been fired the shot firer goes into the mine and opens and locks all switches. He is required to leave in the check cabin a signed statement that the proper switches have been opened.

MISCELLANEOUS DETAILS.

The coal is undercut and is shot down with permissible explosives.

There are about 230 shots fired each day.

The average number of missed shots for one year was 1.13 per cent of the shots connected.

Some of the shots are connected in series and some in multiple. The selection is optional with the shot firer.

All the shots in the mine are fired at once.

COST OF OPERATION.

The operators of the mine using system 4 state that in 1913 the cost of maintaining the shot-firing system was approximately 1.4 cents per ton of coal mined.

They also state that the cost of shot inspectors would be incurred regardless of how the shots are fired, and hence should not be charged to the operation and maintenance of the electric shot-firing system.

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SYSTEM 5.

CHECK CABIN.

The check cabin of the mine using system 5 is situated near the entrance to the mine and is provided with an attendant. The miner hangs his identification check on the check board when entering the mine and removes his check when he leaves the mine.

SOURCE OF POWER.

The 500-volt direct-current power used for firing the shots is taken from a 150-kw. generator in the power house.

SHOT-FIRING CIRCUITS.

The trolley wires and feeders and the regular ground return are used for the main shot-firing circuit. Special branch circuits are installed as extensions beyond the end of the power wires. One side of the extended circuits is connected to the trolley wire or feeder and the other side is connected to the rail. A double-pole switch is used. The room circuits are tapped at each room neck from the branch circuits. A loop or by-pass circuit that includes the firing switch for the control of the system when used as a firing system is connected to each side of the main switch that controls all the underground power circuits. The by-pass circuit runs from the main switch to the shot-firing cabin, a small wooden inclosure in which the shot-firing switch is installed.

For the branch circuits No. 8 (B. & S.) rubber-covered wire is used, and for the room circuits No. 14 (B. & S.) rubber-covered copper wire. The branch circuits are supported on porcelain insulators fastened to short cross-arms secured to the roof. The room circuits are supported on props by means of wooden clamps or nails.

SWITCHES.

As the power circuit is used for shot firing, all of the power switches are included in the shot-firing circuit, but the only switches that are used for shot-firing purposes are the double-pole switches inclosed in locked boxes, where the shot-firing circuits are extended beyond the power circuits, the firing switch, and the single-pole switch that connects the firing switch in multiple with the main power-control switch. It is therefore seen that ordinarily during the major part of the day shift the branch circuits to which the shots are connected or are about to be connected are separated from the 500-volt source of power only by the double-pole switches at the end of the power circuits. The firing switch is installed in the shot-firing cabin, a

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small locked wooden inclosure, near the entrance to one of the escape ways. There are no room switches, as no power wires extend beyond the double-pole switches that control the branch circuits. As the power wires are used for the main shot-firing circuit the gap in the circuit for lightning protection can not be used.

METHOD OF OPERATION.

The pick miners connect their own shots, but the shots of the machine miners are connected by men delegated solely for that purpose. When the shot firer has ascertained by examining the check board that all the miners are out of the mine, he goes in and opens the main switch that controls all the underground power circuits. He then closes all the switches on the shot-firing circuits that are extended beyond the power lines, and as he leaves the mine he closes the single-pole switch that connects the firing switch to the source of power. He then proceeds to the shot-firing cabin and unlocks and closes the firing switch, immediately reopening and locking it. He then reenters the mine and opens and locks all the switches on the shot-firing-circuit extension.

MISCELLANEOUS DETAILS.

The coal is undercut and is shot down with permissible explosives.
All the shots in the mine are fired at once.
About 150 shots are fired each day.
The average proportion of missed shots is 4.1 per cent.
Some of the detonators are connected in series and some in multiple.

COST OF OPERATION AND MAINTENANCE.

Data in regard to the cost of operation and maintenance are presented in the description of system 6 (p. 17).

SYSTEM 6.

CHECK CABIN.

The check cabin in the mine using system 6 is situated about 100 feet from the manway entrance. Safety lamps are used in this mine. When the miner calls for his lamp, he gives the lamp man his identification check. When the miner returns his lamp in the evening, his check is returned to him.

SOURCE OF POWER.

The 500-volt direct-current power used for firing the shots is taken from the 150-kw. generator in the power house.

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SHOT-FIRING CIRCUITS.

The trolley wires and feeders and the regular ground return are used as the main shot-firing circuit. In each cross entry a branch circuit is extended to the face of the entry beyond the end of the trolley wire. Connection between the trolley wire and the track rail is made through the two double-pole switches in series. The room circuits are tapped from the extended branch circuits.

For the branch circuits No. 8 and No. 10 (B. & S.) wire is used. Some of the circuits have weatherproof insulation and some rubber insulation. For the room circuits No. 14 (B. & S.) copper wire is used.

The branch circuits on the entries are supported on porcelain knobs fastened to short cross arms secured to the roof. Wherever the shot-firing circuits cross trolley wires or other live wires, a switch is placed in the shot-firing circuit on either side of such wires. Both of the switches are locked open except during shot firing. This method of protecting the shot-firing circuits where they cross live wires is the best that has come to the bureau's attention.

The room circuits are fastened with wooden cleats to the props.

SWITCHES.

As the power circuit is used for shot firing, all the power switches are included in the shot-firing circuit, but the only switches that are really used in connection with the shot firing are the two double-pole switches (one locked) on each cross-entry branch circuit and the firing switch in the shot-firing cabin. There are no room switches, as no power wires extend beyond the double-pole switches that control the branch circuits. The firing switch is placed in the shot-firing cabin, a small wooden inclosure, and is locked open except when shots are to be fired. Therefore during the day shift there are between the shots and the source of power only the two switches that connect the branch circuits, on the cross entries, to the trolley circuits. As the power wires are used for shot firing, the gap in the circuit can not be used for lightning protection.

METHOD OF OPERATION.

The miners connect their own shots. The shot firers go into the mine at 1 p. m., when they measure the undercutting and the shot holes and distribute the detonators. After the completion of these duties they go to the telephone and wait until the checkman telephones to them that all the men are out of the mine and that the power has been shut off by the opening of the shot-firing switch. Then the shot firers at once go over the mine and close all the switches that connect the branch shot-firing circuits to the power line, and leave

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the mine. As soon as they are outside they switch on the danger signals, red electric lamps, and after waiting about 10 minutes one of them proceeds to the shot-firing cabin and unlocks and closes the shot-firing switch, which he immediately reopens and locks. After the shooting has been done all the shot firers reenter the mine and open and lock all the switches on the shot-firing circuit.

MISCELLANEOUS DETAILS.

The danger signals consist of red lights placed at the entrance to the mine and at the shot-firing cabin.

All the shots in the mine are fired at once.

The detonators are connected in multiple.

The missed shots are fired the following day.

There are about 165 shots fired each day.

There are about 4.1 per cent of missed shots.

COST OF OPERATION AND MAINTENANCE.

The mine officials state that there is only one man directly chargeable to the shot-firing system. The other employees are necessary, no matter how the shots are fired. The following statement furnished by the officials of the mine where the system is installed shows the cost of the system:

Information regarding the operation of system 6.

Month.	Quantity of coal mined.	Quantity of powder used.	Number of shots fired.	Number of shots missed.	Cost of labor and materials.	Cost per ton of coal mined.[a]
1913.	*Tons.*	*Pounds.*				
July	48,298	4,900	5,182	224	$343.44	$0.0071
August	43,653	4,925	4,800	173	413.03	.0094
September	43,670	3,875	4,854	188	185.39	.0041
October	52,617	5,975	6,016	202	362.05	.0068
November	60,292	6,200	6,476	310	327.61	.0053
December	63,472	6,275	5,853	281	303.18	.0047
1914.						
January	62,032	7,125	6,935	238	277.82	.0045
February	56,695	5,900	6,710	355	176.72	.0030
March	66,400	6,175	8,162	461	617.95	.0093
April	60,987	5,875	7,262	367	889.40	.0145
May	64,924	5,100	7,556	283	628.40	.0096
June	73,731	5,875	8,167	400	585.65	.0081
Total	696,671	38,200	79,053	3,482	5,120.64	[b]0.0074

[a] The cost figures here given are essentially the same for system 5. [b] Average.

SYSTEM 7.

CHECK CABIN.

The check cabin in the mine using system 7 is 200 feet from the mine entrance and is in charge of an attendant. Each miner has an identification check which he deposits at the check cabin when

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he enters the mine and which the checkman returns to the miner when he leaves the mine.

SHOT-FIRING CABIN.

The shot-firing cabin is a small wooden inclosure for the shot-firing switch and is placed near the mine entrance.

SOURCE OF POWER.

The 230-volt alternating-current power used for firing the shots is supplied by three large transformers in the substation.

SHOT-FIRING CIRCUITS.

The main shot-firing circuit runs from the substation to the shot-firing cabin and thence by the return airway into the mine. A branch circuit is tapped from the main circuit at each cross entry and runs to the face of the entry. The room circuits are tapped from the branch circuits at the room necks. For the main and branch circuits that exceed 1,000 feet in length No. 4 (B. & S.) rubber-covered copper wire is used. In short cross entries No. 6 (B. & S.) copper wire is used. No. 14 (B. & S.) copper wire is used in the rooms.

The main circuit and all branch circuits, both in entries and in rooms, are supported on porcelain knobs fastened to the props or to wooden plugs driven into holes in the coal.

SWITCHES.

The shot-firing circuits are controlled by the following switches: One double-pole switch in the substation; one double-pole switch in the shot-firing cabin; and two at each cross entry. In addition to these switches, wherever the shot-firing lines cross the trolley wire or other power wires, two switches are placed in the shot-firing circuit, one on each side of the entry. All switches, except one of the two at each cross entry, are in locked boxes.

There are no room switches, although there are power wires on the cross entries. There is in the shot-firing circuit no gap as a protection against lightning.

METHOD OF OPERATION.

The shot inspectors, who are also the shot firers, go into the mine at 1 p. m. and distribute the detonators. The miners connect their own shots. When the shot inspectors have completed these duties, they call the check man on the telephone and ascertain whether all the men are out of the mine. As soon as they are advised that all

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the men are out of the mine the shot inspectors go over the mine, closing all the switches on the shot-firing circuits. They then meet and leave the mine together. The attendant in the substation is then told to close the switch that connects the shot-firing circuit to the source of power. The shot firer then proceeds to the shot-firing cabin, where he unlocks and closes the firing switch, immediately reopening and locking it. After the shots have been fired the shot inspectors again go into the mine, opening the shot-firing switches as they go. The missed shots, if not too numerous, are not fired until the next day.

MISCELLANEOUS DATA.

Many times there are no missed shots.
All the shots in the mine are fired at once.
The detonators are connected in multiple.
The average proportion of missed shots is 0.95 per cent.
The coal is undercut and is shot down with permissible explosives.
From 75 to 110 shots are fired each day.

COST OF OPERATION.

The company using system 7 operates electric shot firing in five of its mines. The information given in the table following was supplied by the mine officials and represents the average results obtained in two of its mines.

Information regarding costs and number of shots fired and missed in two mines using system 7.

Month.	Quantity of coal mined.	Number of shots fired.	Number of shots missed.	Cost of labor and materials.	Cost per ton of coal mined.
1913.	*Tons.*				
July					
August					
September	34,700	5,363	39	$229.44	$0.66
October	36,486	6,428	42	213.46	.58
November	41,370	7,583	36	291.05	.70
December	40,900	7,078	115	190.52	.46
1914.					
January	27,466	4,397	45	318.20	1.16
February	17,836	2,895	32	62.30	.35
March	13,649	1,878	16	24.00	.17
April	12,882	1,879	24	44.72	.35
May	13,402	2,414	24	33.57	.60
June	19,025	2,717	33	43.08	.23
Total	257,716	42,632	406	1,450.24	[a].526

[a] Average.

SYSTEM 8.

CHECK CABIN.

The check cabin of the mine using system 8 is near the mine. The miners as they enter the mine hang their identification checks on the check board and as they leave the mine take their checks with them.

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SHOT-FIRING CABIN.

The shot-firing cabin, which contains the shot-firing switch, is a small wooden inclosure near the entrance to the mine.

SOURCE OF POWER.

The 224-volt alternating current used for firing the shots is supplied by a transformer.

SHOT-FIRING CIRCUITS.

The main circuit runs from the power house to the shot-firing cabin and thence into the mine. The branch circuits are tapped from the main circuit at each cross entry. The room circuits are tapped from the branch circuits at each room neck.

For the main circuit and all branch circuits No. 6 (B. & S.) rubber-covered copper wire is used.

For the room circuits No. 14 (B. & S.) rubber-covered copper wire is used.

The main and branch circuits are supported on porcelain knobs fastened to short cross arms secured to the roof. The room circuits are supported on porcelain knobs fastened to wood plugs driven into the coal.

SWITCHES.

The shot-firing circuits are controlled by the following switches: One double-pole switch in the power house; one double-pole switch and circuit breaker in the shot-firing cabin; two double-pole switches in series at each cross entry, where there is also placed a single-pole switch for short circuiting the branch circuits when the double-pole switches are open. Wherever the firing circuits cross the trolley or other live wires a double-pole switch is installed in the firing circuit on each side of the trolley wire and kept open except at the time of firing. This practice reduces to a minimum the danger of stray currents from power wires. All switches except one of the two at each cross entry are in locked boxes. There are no room switches, although there are power wires on the same entry as the branch shot-firing circuits. There is in the shot-firing circuit no gap as a protection against lightning discharges.

METHOD OF OPERATION.

Shot inspectors distribute the detonators and inspect the undercutting and depth of holes, but the miners connect their own shots. After all the men have been checked out of the mine, the shot firer enters and closes all switches on the shot-firing circuits with the

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exception of the branch-entry short-circuiting switches, which, of course, he opens. The shot firer then leaves the mine and instructs the power-house attendant to close the switch that connects the shot-firing system to the source of power. The shot firer then goes to the shot-firing cabin and unlocks and closes the circuit breaker and the firing switch, both of which he immediately reopens and locks. The shot firer then enters the mine and opens all switches on the shot-firing circuits, and short-circuits the branch-entry circuits.

MISCELLANEOUS DATA.

The coal is undercut, and is shot down with permissible explosives.
The detonators are connected in series.
There are about 250 shots fired each day.
All the shots in the mine are fired at once.
There are about 2 per cent of missed shots. These are fired the same night.

COST OF OPERATION.

It is stated by the mine officials that the cost of firing the shots is approximately 1½ cents per ton of coal mined.

SYSTEM 9.

CHECK CABIN.

The check cabin of the mine using system 9 is about 150 feet from the entrance to the mine. An attendant takes care of the check board. The miners as they enter the mine deposit their identification checks, which are returned by the attendant as they leave the mine.

SHOT-FIRING CABIN.

The shot-firing cabin, a wooden structure about 6 feet square, is near the entrance to the mine. It contains nothing but the shot-firing switch and wires.

SOURCE OF POWER.

The 250-volt direct-current power used for firing the shots is taken from the switchboard in the substation and is supplied by the regular power generators.

SHOT-FIRING CIRCUITS.

The trolley wires and feeders and the regular ground return are used for the main shot-firing circuit. Special branch circuits are installed as extensions beyond the end of the power wires. One

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side of this extended circuit is connected to the trolley wire or feeder and the other side to the rail. A double-pole switch is used. The room circuits are tapped from the branch circuits at each room neck.

For the branch circuits No. 8 (B. & S.) rubber-covered copper wire is used, and for the room circuits No. 14 (B. & S.) rubber-covered copper wire. The branch circuits are supported on porcelain knobs fastened to short cross arms secured to the roof. The room circuits are supported on porcelain cleats and small wooden clamps secured to the props.

SWITCHES.

As the power circuits are used for shot firing, all of the power switches are included in the shot-firing circuit; but the only switches that are used in connection with the shot firing are the main switch in the power house, the shot-firing switch, which by-passes the power switch at the mine entrance, the double-pole switches that connect the ends of the trolley circuits to the extended shot-firing circuits, and a single-pole switch and the ground wire at that point. The two switches last mentioned are the only ones between the power supply and the circuits to which the detonators are connected, as there are no room switches. All of the switches are in locked boxes except the single-pole switch on the ground wire. As the power wires are used for the main shot-firing circuit, a gap in the circuit for lightning protection can not be used.

METHOD OF OPERATION.

When all the men are out of the mine, the electric current is shut off the entire mine circuit by opening the switch in the substation. The shot firers then take a supply of detonators and enter the mine. They measure the undercutting and the depth of the shot holes, and if these are satisfactory they tamp the shots and connect them to the room wires. When all the shots are tamped and connected, the shot firers meet and leave the mine together, closing all the switches as they go. When they reach the outside, the attendant in the substation is told to close the switch that connects the shot-firing switch to the source of power. The shot firer goes to the shot-firing cabin and unlocks and closes the firing switch, then immediately reopens and locks it.

After the shots are fired the shot firers again go into the mine, opening the shot-firing switches as they go. Any missed shots found are disconnected and left until the next day.

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MISCELLANEOUS DETAILS.

All the shots in the mine are fired at once.

The coal is undercut and is shot down with permissible explosives.

The detonators are connected in multiple.

The following table shows for one month the number of shots fired per day and the number of shots missed and the cause of the failure:

Information regarding the operation of system 9.

Month.	Day.	Shots fired.	Shots missed.	Cause of missed shot.
July	25	140	0	
Do	27	127	2	One, bad cap; one, bad connection.
Do	28	141	0	
Do	29	126	1	Broken wire.
Do	30	151	2	One, bad cap; one, bad connection.
Do	31	137	0	
August	1	121	2	Bad connection.
Do	3	104	1	Do.
Do	4	123	0	
Do	5	104	0	
Do	6	130	0	
Do	7	129	0	
Do	8	104	0	
Do	10	113	0	
Do	11	129	0	
Do	12	123	1	Do.
Do	13	134	0	
Do	14	147	2	Do.
Do	15	100	0	
Do	17	136	0	
Do	18	151	0	
Do	19	140	[a] 2	
Do	20	141	0	
Do	21	157	5	Do.
Do	22	121	0	
Do	24	152	3	Two, wet shots; one, broken wire.
Total		3,381	21	

[a] Three attempts made to fire these shots.

COST OF OPERATION.

The company uses electric shot-firing systems in five of its mines, and its officials state that the cost of operating the shot-firing system for the year ended June 30, 1914, was 1.55 cents per ton of coal mined. This statement is based on the operation of four mines for one year and one mine for four months.

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SUMMARY OF INFORMATION OBTAINED.

The table following summarizes the information set forth in the preceding pages:

Summary of information in regard to nine outside shot-firing systems investigated.

System No.	Is check system used?	Source of power.		Are power wires used for shot-firing circuits?	Is shot-firing system grounded?	Distance from source of power to center of load.[a]	Size of main shot-firing conductors (B. & S. gage).	Size of cross-entry shot-firing conductors (B. & S. gage).	Size of room shot-firing conductors (B. & S. gage).	Are insulators used on main shot-firing circuits?	Are insulators used on cross-entry shot-firing circuits?	Are insulators used on room shot-firing circuits?
		Volts.	Current.									
						Feet.						
1	Yes.	500	Direct	No.	No.	13,200	4, 6, 10	10	14	Yes	Yes.	No.
2	Yes.	175	do	No.	No.	1,000	10	[b] 12	[c] 10	Conduit	No[b].	No.
3	No.	500	do	No.	No.	1,600	6	12	12	No [d]	No[d].	No. [d]
4	Yes.	550	do	Yes.	Yes.	8,500	4/0	6, 10, 12	14	Power wire used.	Yes.	No.
5	Yes.	500	do	Yes.	Yes.	[e] 11,000	4/0	8	14	do	Yes.	No.
6	Yes.	500	do	Yes.	Yes.	13,200	[f] 250,000	8, 10	14	do	Yes.	No.
7	Yes.	230	Alternating.	No.	No.	[e] 3,000	4	4, 6	14	Yes	Yes.	No.
8	Yes.	244	do	No.	No.	2,500	6	6	14	do	Yes.	Yes.
9	Yes.	250	Direct	Yes.	Yes.	7,920	4/0	8	14	Power wire used.	Yes.	Yes.

System No.	Are switches used at each cross entry?	Are switches used at entrance to rooms?	Are there power wires beyond the entry switches?	Is a lightning gap used?	Minimum number of gaps between shots and source of power at time of connecting shots.[g]	Who connects shots?	Are shots connected in multiple or series?	Number of shots fired daily.	Percentage of missed shots. [a]	Increase in cost of operation as compared with other systems, cents per ton of coal.[a]
1	No	No.[h]	Yes.	Yes.	4	Miner	Multiple	158	5	0.8
2	Special relay	No.	No.	Yes.	[i] 5	do	do	200	2	(j)
3	Yes	No.	No.	Yes.	4	Shot firer	do	135	(j)	(j)
4	Yes	No.	Yes.	No.	2	Miner	Series and multiple.	230	1.5	1.3
5	Yes	No.	No.	No.	1	Miner and shot firer.	do	150	4.4	.75
6	Yes	No.	No.	No.	2	Miner	Multiple	165	4.1	.75
7	Yes	No.	Yes.	No.	4	do	do	150	.95	.52
8	Yes	No.	Yes.	No.	5	do	Series	250	2	1.5
9	Yes	No.	No.	No.	2	Shot firer	Multiple	130	.62	1.55

[a] Based on statements made by mine officials.
[b] No. 12 deplex wire run under ball of rail. Mine extremely dry.
[c] Iron wire, protected.
[d] Small wooden clamps used. Mine extremely dry.
[e] Estimated by the bureau's representative.
[f] Circular mils.
[g] Either a single-pole or a double-pole switch, or the equivalent of either, is considered as a gap.
[h] Plug connections used; equivalent to switches.
[i] Generator not started until all the men are out of the mine.
[j] Information regarding this detail not available.

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CONSTRUCTION AND PRACTICES RECOMMENDED.

As the firing circuits of an outside firing system are a permanently installed network of wires that extends over a large area and is exposed to various untoward influences and possible mishandling by many people, various switches and safety devices must be used in connection with the system.

It is also essential that there be provided effective means for insuring that no one is in the mine when the shots are fired.

FACTORS CONTRIBUTING TO THE SUCCESS OF AN OUTSIDE SYSTEM.

In order to insure safe and successful operation an outside system must be so installed as to insure the following desirable conditions:

1. Freedom from accidental connection with its source of power.
2. Freedom from stray currents from other sources of electricity.
3. Freedom from connection to the earth.
4. Freedom from short circuits between the two sides of the shot-firing circuits.
5. Freedom from open circuits when shots are to be fired.

Freedom from accidental connection to the source of power requires that several switches placed at different points shall be connected in series with the line, and that these be closed in predetermined order, and only by the men authorized to do so.

Freedom from stray currents requires that only properly insulated conductors be used for the shot-firing circuits, and that such circuits be properly installed and protected from roof falls and where crossing or passing near other electric circuits.

Freedom from ground connections is desirable because such connections allow the firing current to be diminished by leakage and at the same time provide a path by which stray currents may reach the firing circuits.

Freedom from short circuits on the firing line or from even moderate leakage between the two sides of the firing circuit is essential to the proper distribution of current to the detonators or fuses.

Freedom from open circuits in the system at the time of firing is manifestly necessary to the discharge of all the shots.

SUGGESTED SPECIFICATIONS FOR AN OUTSIDE SHOT-FIRING SYSTEM.

There follows a series of recommendations concerning the equipment and methods of operating an outside shot-firing system. Such a system may for consideration be divided into five parts, as follows: The checking system, the source of power, the shot-firing panel, the distributing circuits, and the switches.

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CHECKING SYSTEM.

It is quite essential that a system for checking men in and out of the mine shall be used in connection with outside shot-firing systems. The system need not be complicated, but should be efficient and accurate. Most of the checking systems previously described should give satisfactory results if administered properly. It is manifest that any system that is based upon the memory of an individual can not be as safe as a system that gives visible evidence of the number of men that are underground.

SOURCE OF POWER.

The main requisite of the source of power is sufficient capacity. The source may supply alternating or direct current, and may be a generator or a transformer, but its capacity must be great enough to provide the necessary current to the detonators connected to it. The capacity required will depend upon the number of detonators to be discharged, but a momentary capacity of not less than 30 kw. should be sufficient for the average size mine. The voltage required for the supply will depend upon the length of the distributing circuits and the size of wire used, as well as upon the number of detonators to be fired. Under most conditions 250 volts will suffice, but where distances are great and a large number of detonators are to be fired it may be necessary to use 500 volts. If a special generator is provided for shot firing, it should be compound wound.

SHOT-FIRING PANEL.

The shot-firing panel may be regarded as the outside terminal of the shot-firing system as well as the means of putting the system into operation. The bureau recommends that the panel be provided with two single-pole circuit breakers, an ammeter, and a double-pole switch arranged to be locked open.

If the source of power is close by the mine the shot-firing panel may well be placed in the power house.

If this is not feasible, or if the source of power is too far from the mine, the shot-firing panel should be provided with suitable housing and with means for disconnecting it entirely from the source of power.

DISTRIBUTING CIRCUITS.

CONDUCTORS.

The conductors of distributing circuits should always be covered with insulating material. Unless the mine is dry, rubber-insulated wire should be used. The size of the wire that will be required for

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distributing circuits depends upon the available firing voltage, the number of detonators to be shot, the method of connecting the detonators, and the length and arrangement of the circuits. A change in any of these factors will, if the conductors have no factor of safety in their dimensions, make a difference in the size of wire that it is desirable to use. Therefore, in order to make a brief recommendation, it is necessary to assume values for some of the variables entering into the problem, and in order to make recommendations that will be generally applicable the values must be assumed great enough to cover the most difficult case.

The bureau recommends that shot-firing conductors in rooms be not smaller in size than No. 14 (B. & S.) gage, that those in cross entries be not smaller than No. 10 (B. & S.) gage, and that those used between entries be not smaller than No. 8 (B. & S.) gage. The recommendations for the size of wire for the remainder of the shot-firing circuit—the line connecting the source of power to the first entry to be shot—are based upon the assumption that the above-mentioned minimum values are used and upon the following assumption as to the dimensions and arrangement of the mine entries and rooms:

Maximum length of cross entry	feet..	3,000
Distance between cross entries	do....	500
Number of pairs of cross entries		6
Maximum length of rooms	feet..	400
Distance between rooms	do....	50
Maximum number of shots to be fired		300

It is further assumed that three shots will be fired in each room and that the shots will be connected in multiple, as the bureau recommends.

Lengths of various sizes of wire between source of power and first entry allowable when shooting with 250 volts and 500 volts are given in the table following:

Allowable length of wires.

Size of wire (B. & S. gage).	Distance from source of power to first entry for—	
	250 volts.	500 volts.
	Feet.	*Feet.*
8.....	1,500	4,500
6.....	2,500	7,000
4.....	4,000	11,000

The allowable length may be increased somewhat if the cross entries are less than 3,000 feet long, if the rooms are less than 400 feet long, or if wires larger than those assumed are used in the rooms,

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in the entries, or between the entries. A decrease in the number of shots will not increase materially the allowable length of conductors between the first entry and the source of power.

INSULATION OF CONDUCTORS.

The insulation of the conductors of the shot-firing circuits will depend somewhat on the voltage used for firing and somewhat on the conditions of the mine as to dampness. In order to insure satisfactory operation the conductors of the main circuit should be installed on insulators. The voltage on the branch circuits will rarely exceed about 100 volts, except for the brief interval between the discharge of the shots and the opening of the firing switch in the shot-firing cabin. Therefore, although the use of insulators on the branch circuits is recommended, it is probable that systems which do not use insulators will operate successfully under favorable conditions. Except for the interval mentioned above, the potential in the rooms will not exceed 5 volts approximately, and therefore porcelain or glass insulators are not necessary if the rooms are dry and the wires are supported on dry wood.

It is desirable to install the shot-firing conductors in entries where there are no other wires, and wherever the conductors of the shot-firing system cross live wires adequate precaution should be taken to prevent leakage of current to the shot-firing wires. An excellent method that has been adopted in some mines to prevent such leakage is the installation of switches in the shot-firing circuit on either side of any other circuit that it crosses. These switches can be kept open ordinarily, preferably by locking in that position, and closed when the rest of the switches in the underground system are closed.

USE OF POWER WIRES NOT RECOMMENDED.

The use of power wires as part of the shot-firing system is not recommended because such a practice precludes the use of safeguards that the bureau engineers consider desirable, thus reducing the factor of safety of the system. If power wires are used for shot firing it is scarcely practicable to have more than one open switch between the detonator and the firing system, unless switches are installed at the entrance of each room. Thus the discharge of shots during working hours is possible and has been reported. The use of power wires also precludes the use of a large gap in the circuit as a protection against lightning discharges. The use of such a gap is recommended as being simpler and more effective than lightning arresters, which of course are the only available means of lightning protection for circuits that, like power circuits, can not be interrupted.

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SUITABLE GAP FOR PROTECTION AGAINST LIGHTNING.

A suitable gap may be provided by inserting in each side of the circuit, near the bottom of the shaft or the slope, or about 100 feet inby from the mouth of the drift, a flexible conductor about 6 feet long. Each of these conductors can be permanently joined to the end of one of the solid incoming conductors and the other end of each flexible conductor can be provided with a lug for fastening to one of a pair of screw studs in which the outcoming solid conductors should terminate. A similar pair of dummy studs should be installed 6 feet distant from the live studs so as to provide a place for fastening the flexible conductors out of circuit. The dummy studs should be provided with a locked clamp or similar device for locking the flexible conductors out of circuit.

SHOOTING FROM GROUNDED SYSTEM.

It is dangerous to connect one side of a detonator to earth before it is to be fired. Shooting from a grounded system does not necessitate making a connection of this sort, because connection between the source of power and the shot-firing system should not be made until it is time to fire the shots. There is therefore no objection to firing from a grounded system if the underground shot-firing circuits are entirely separate from the power circuits.

SWITCHES.

It is recommended that between the detonators and the source of power there be at least four switches, or their equivalent, situated as follows: One at each cross entry to protect the entry from any current leakage that might take place at any other point, a 6-foot gap at the mine entrance to protect against lightning and to form one of three breaks in the main circuit; one for connecting the shot-firing system to the source of power, and one on the shot-firing panel for finally closing the circuit and causing the shots to discharge. If there are power wires on the cross entries beyond the entry switches, means should be provided for opening the firing circuit at each room. This recommendation is made to protect the miner from the effects of leakage between the entry power wires and the shot-firing circuit. All switches except room switches should be designed so that they can be locked open.

Means should be provided to insure that power is applied to the shot-firing system only once and for a brief interval (not to exceed three seconds). If the shots will fire at all they will do so within three seconds from the time the switch is closed. A second closing of the firing switch serves no useful purpose and may cause flashes in the rooms if the conductors of the firing circuits have been brought in contact as the result of the shooting.

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OPERATION OF THE SYSTEM.

CONNECTION OF SHOTS.

So far as the authors have been able to learn from the report of systems in actual use the failure of shots to fire is due largely to the fact that the electrical connection between room wires and detonators is not properly made. It is therefore recommended that these connections be made after the miners have left the mine by men specially delegated for the duty. This practice has been followed in some mines with seemingly very satisfactory results.

Experiments that the bureau has just completed indicate that fewer failures to fire will occur if the detonators are connected in multiple in the rooms than if they are connected in series.

OPERATION OF SWITCHES.

The operation of all underground shot-firing switches should be in the hands of duly authorized men, who should attend to this duty after they have connected the detonators. It is recommended that one man be made responsible for the operation and upkeep of the shot-firing system, and that all other men having duties in connection with the system be under his supervision. After these men have left the mine they should examine the check board to insure that all men are out of the mine before the switch that connects the shot-firing system to the source of power is closed. After it is assured that all the men have left the mine the shot-firing panel may be connected to the source of power, and then the shots may be fired by closing the switch on the shot-firing panel. This switch should be closed only once and should not be kept closed for more than five seconds. All working places where shots have been fired should be examined for fire and misfires as soon as possible after the shots have been fired. All switches in the shot-firing system should be opened before the miners are allowed to go into the mine. The man who fires the shots should, before going off duty, record in a book provided for the purpose the number and location of all shots that have failed to fire.

COST OF OPERATION.

The bureau has no information as to the basis of all the cost figures given in the table on page 24, but those that are known are based on the excess cost of labor and material, etc., for operating the outside system as compared with charges incident to firing shots electrically from inside the mine. The figures are therefore a statement of the excess cost per ton for the outside system over that of any other electrical system. So far as the bureau is aware no account has been taken of charges for interest on the investment or for depreciation of equipment.

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COST OF INSTALLING AN OUTSIDE SHOT-FIRING SYSTEM.

The following estimate covers equipment from the point where power is supplied to the shot-firing panel mentioned below, but does not include cost of materials or labor for constructing the line between this panel and the source of power, which, of course, in some cases may be a considerable distance from the panel.

Neither does the estimate cover the cost of material and labor for any surface wiring for connection between the shot-firing panel and the entrance to the mine. Local conditions will affect so much the cost of this part of the system that a reasonable estimate can not be made.

The estimate does include, however, cost for underground lines from the pit mouth to the first entry to be fired, as well as the cost of the branch circuits and the main circuit between entries.

Detailed estimate of the minimum cost of installing an outside shot-firing system.

	Weather-proof.	Rubber covered.
One shot-firing panel equipped with two 100-ampere 500-volt single-pole circuit breakers, one 0–100 ampere ammeter, one 100-ampere 500-volt double-pole switch (arranged to be locked in open position), iron-pipe supports, wall braces 3 feet long, and necessary wiring		$85.00
Lightning gap (to be situated underground where the main shot-firing circuit enters the mine)		5.00
Cross-entry switches, double-pole, single-throw, 250-volt, 50-ampere, with porcelain base, mounted in locked box, each		2.50
Underground main circuit (per 1,000 feet):		
Using No. 8 wire—		
2,000 feet of No. 8 wire (minimum size recommended)	$23.00	$48.00
Insulators	3.00	3.00
Labor	20.00	20.00
	46.00	71.00
Alternative, using No. 6 wire—		
2,000 feet of No. 6 wire	33.71	64.00
Insulators	3.00	3.00
Labor	20.00	20.00
	56.71	87.00
Branch circuits (per 1,000 feet):		
2,000 feet of No. 10 wire (minimum size recommended)	17.00	36.50
Insulators	3.00	3.00
Labor	20.00	20.00
	40.00	59.50
Room circuits (length of room, 400 feet), 850 feet of No. 14 weather-proof wire	4.25	.....
Room switches (if used), double-pole, single-throw, 250-volt, 50-ampere switches mounted on slate bases fastened to timbering or plugs driven in the coal		1.25

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The labor involved in installing room circuits will be largely a maintenance charge, as the wires will be extended from day to day. It is scarcely possible to make an estimate of this charge that will be generally applicable.

CONCRETE EXAMPLE OF TOTAL COST OF INSTALLING SYSTEM.

In order to give a concrete example of the cost of installing an outside shot-firing system, the following assumptions have been made:

Number of active cross entries		8
Number of rooms to be wired		150
Distance from shot-firing panel to pit mouth	feet	500
Distance from pit mouth to first entry	do	2,000
Distance from first entry to face	do	2,000
Average length of entries	do	1,000
Average length of rooms	do	200

It is also assumed that the character of the roof or side of entries is such as to offer favorable conditions for installing the conductors and that competent wiremen are available for doing the work.

On this basis the cost of an outside shot-firing equipment, exclusive of the source of power, but including a shot-firing panel, lightning gap, eight cross-entry switches, the necessary surface main line, underground main line, underground branch circuits, 150 room equipments, and labor of installation has been estimated as follows for a mine like that assumed, equipped as just stated:

Complete with rubber-covered wire and room switches, about	$1,700
Complete with rubber-covered wire without room switches, about	1,500
Complete with weatherproof wire and room switches, about	1,400
Complete with weatherproof wire and no room switches, about	1,200

SUMMARY.

ESSENTIAL FEATURES OF OUTSIDE SHOT-FIRING SYSTEMS.

The recommendations contained in this paper concerning outside shot-firing systems are essentially as follows:

CHECKING SYSTEM.

An outside firing system should not be used without a suitable checking system.

SOURCE OF POWER.

The source of power should have a momentary capacity of not less than 30 kw. for a mine of average size. It may supply either alternating or direct current.

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FIRING VOLTAGE.

It is recommended that 250 volts be used where conditions permit, but 500 volts must be used where distances or the number of shots to be fired exceed the limits that can be satisfactorily handled by 250 volts.

SHOT-FIRING PANEL.

The shot-firing panel should be well mounted and housed and should be provided with two single-pole circuit breakers, a double-pole switch, and an ammeter. A switch should also be provided for disconnecting the panel from the source of power.

DISTRIBUTING CIRCUITS.

Wires of power circuits should not be used for shot-firing conductors if such a practice reduces the factor of safety of the system.

All shot-firing conductors should be insulated.

All parts of the shot-firing circuits should be supported on insulators. Dry wood will be satisfactory for the insulators of room wires, but is not recommended for any other part of the circuit.

Conductors should not be less than No. 14 (B. & S.) gage in rooms, No. 10 in cross entries, and No. 8 elsewhere.

Each system should be considered by itself in the light of the conditions that surround it, and conductors larger than the minimum recommended should be used if the distances and number of shots involved require the use of larger sizes of wire.

LIGHTNING GAP.

Arrangements should be made so that a large gap, as a protection against lightning, can be opened in each side of the shot-firing circuit underground, at or near the point where the circuit enters the mine.

SWITCHES.

There should be not less than four switches or their equivalent between the detonators and the source of power. At least three of these switches should be locked. The cross-entry switches should be inclosed in locked boxes.

MAKING DETONATOR CONNECTIONS.

Detonators should be connected in multiple.

Connection between detonators and the room wires should be made by men specially commissioned to perform this duty.

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PUBLICATIONS ON MINE ACCIDENTS AND METHODS OF COAL MINING.

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BULLETIN 17. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 61 pp., 10 pls., 12 figs. Reprint of United States Geological Survey Bulletin 423.

BULLETIN 20. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 204 pp., 14 pls., 28 figs.

BULLETIN 42. The sampling and examination of mine gases and natural gas, by G. A. Burrell and F. M. Seibert. 1913. 116 pp., 2 pls., 23 figs.

BULLETIN 45. Sand available for filling mine workings in the Northern Anthracite Coal Basin of Pennsylvania, by N. H. Darton. 1913. 33 pp., 8 pls., 5 figs.

BULLETIN 46. An investigation of explosion-proof mine motors, by H. H. Clark. 1912. 44 pp., 6 pls., 14 figs.

BULLETIN 48. The selection of explosives used in engineering and mining operations, by Clarence Hall and S. P. Howell. 1913. 50 pp., 3 pls., 7 figs.

BULLETIN 50. A laboratory study of the inflammability of coal dust, by J. C. W. Frazer, E. J. Hoffman, and L. A. Scholl, jr. 1913. 60 pp., 95 figs.

BULLETIN 52. Ignition of mine gases by the filaments of incandescent electric lamps, by H. H. Clark and L. C. Ilsley. 1913. 31 pp., 6 pls., 2 figs.

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TECHNICAL PAPER 13. Gas analysis as an aid in fighting mine fires, by G. A. Burrell and F. M. Seibert. 1912. 16 pp., 1 fig.

TECHNICAL PAPER 14. Apparatus for gas-analysis laboratories at coal mines, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 7 figs.

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